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TECHNICAL REPORT 105-41

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REPORT ON
PROJECT ALBEDO, PHASE I

JUNE 1949

HEADQUARTERS
AIR WEATHER SERVICE
WASHINGTON, D.C.

HEADQUARTERS
AIR WEATHER SERVICE
Andrews Air Force Base
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Air Weather Service Technical Report 105-41, "Report on Project Albedo, Phase I", is published for the information of all concerned.

BY COMMAND OF BRIGADIER GENERAL YATES

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Preface

In 1946 the U. S. Weather Bureau recommended to the Deputy Chief of Staff for Research and Development, USAF, that measurements of solar and reflected radiation be made by Air Force weather reconnaissance aircraft in order to provide data for research on the basic problem of the heat budget of the atmosphere. The Air Weather Service was directed by Hq, USAF, to make such measurments if feasible.

The 308th Reconnaissance Group (Weather) was assigned the first phase of the problem - namely, to determine the feasibility of making airborne radiation observations adequate for computing albedos and to develop the technique for them. As the project, designated "Albedo" for convenience, was not given highest priority the work has proceeded slowly.

The following report by the Project Officer covers the successful completion of the above stated objectives and marks the closing of the first phase of the Project. Consideration is being given by interested research agencies to an extended program of albedo studies. This report will acquaint these agencies and the Air Weather Service operating units concerned with what has been accomplished and what can be done.

The cooperation of the Chief, U. S. Weather Bureau, and the continued interest and assistance of Mr. S. Frit, and Mr. T.H. McDonald of the Bureau are gratefully acknowledged.

The Eppley Laboratories, of Newport, R. I. contributed materially to the successful completion of the Project by loan of specially improved pyrheliometers for airborne use. As a result of this collaboration a proven instrument is commercially available for any interested agency.

REPORT ON PROJECT ALBEDO, PHASE I

PURPOSE

In order to make any kind of computations concerning what happens to the radiant energy received by the earth from the sun, accurate measurements must be made of the amount of this energy which is reflected from the various types of surfaces on which it falls. The reflectivity (albedo) of land and water surfaces is fairly well known, having been measured a number of times with some accuracy. Since at any one time a fairly large portion of the earths surface is covered with clouds and haze, it is necessary to know, with the same degree of accuracy, the amount of radiant energy which is reflected and absorbed by clouds and haze layers. Up to the present time no systematic extensive measurments of this quantity have been made. Present computations have been based largely on widely scattered observations made about thirty years ago and on assumptions based on these records. Thus the Project was concerned with checking previous measurements of the albedo of all types of terrain, ocean surface and various cloud types. The loss of radiation as a result of passage through cloud layers was also investigated. It was also necessary to examine and decide upon suitable means of instrumentation and operational procedures to obtain the above measurements in an accurate manner.

ABSTRACT

The project was initiated during February 1947. During the first year equipment was selected, procured, tested and installed in modified aircraft. An operational SOP was prepared.

During the summer and fall of 1948 and later during the period 10 April - 28 April 1949, a number of successful missions were flown from which albedo values were obtained. They included a joint mission with a plane from Inyokern, several cross-country flights over the United States in order to fly over all types of terrain, two missions over water, two plane missions to measure the absorption of clouds, four single-plane missions in conjunction with Weather Bureau solar-radiation stations to measure the loss in radiation resulting from passage through a cloud layer, one mission to measure the absorption of a clear sky and one mission over the cloud system around a well developed low.

A new-type pyrheliometer designed to endure aircraft vibrations was tested for approximately 150 hours while mounted on an RB-29 aircraft. The Brown Recorder functioned properly during all flights. A pyrheliometer mount satisfactory for research purposes was designed and manufactured locally. Work on a new mount satisfactory for routine installation on many reconnaissance aircraft and not requiring an operator was in progress but abandoned when indications were received that such a mount would not be necessary.

All raw data from flights is presently on loan to the U. S. Weather Bureau for reduction and evaluation. It will be returned to Fairfield in reduced form giving actual albedo values.

REQUIREMENTS

In a letter from AWS, subject: "Requirements and Operating Procedure for Project Albedo", dated 28 July 1948 it was requested that until further notice the following operations with their assigned priorities be carried out:

Memorandum On Types Of Meteorological And Terrain Conditions
To Be Covered By Airborne Radiation Measurements

CONDITION	PRIORITIES Between Major Categories	PRIORITIES Within Major Categories
I. Radiation Reflected by (Albedo):		
1. Terrain	3	
a. Mountainous		2
(1) Forest		2
(a) Non-snow covered		2
(b) Snow Covered		2
(2) Non-Forested		2
(a) Non-snow Covered		2
(b) Snow Covered		2
b. Non-Mountainous		1
(1) Forest		1
(a) Non-snow Covered		1
(b) Snow covered		1
(2) Non-Forested		1
(a) Non-snow covered		1
1 Desert		1
2 Cultivated Ground		1
(b) Snow Covered		1
1 Desert		1
2 Cultivated Ground		1
3 Change in snow albedo over a series of days		1
2. Ocean	4	
a. Smooth		2
(1) Clear Sky		2
(2) Cloudy Sky		2
b. Rough		1
(1) Clear Sky		1
(2) Cloudy Sky		1
3. Clouds	1	
a. Stratus-Fog		8
b. Cumulus		7
c. Stratocumulus		5
d. Altocumulus		4
e. Altostratus and Nimbostratus		2
f. Cirrus		3
g. Cumulonimbu		6
h. Cloud systems (circuit around a cyclone)		1
II. Radiation Absorbed by:	2	
1. Atmosphere		3
2. Cloud		1
3. Ground		2

In addition the following development and testing was assigned by 4th Ind., dated 1 Nov 1948 to basic letter from Headquarters Air Weather Service, subject: "Procedure for Computing albedos from Pyrheliometer Measurements", dated 27 September 1948:

a. Testing of the new model Eppley pyrheliometers in conjunction with the manufacturer.

b. Development of a standard mounting and aircraft modification for pyrheliometers.

c. Testing of the recorders for use with pyrheliometers.

d. Development of an observing and elementary reducing procedure with forms for reporting pyrheliometer observations, such that using research agencies may complete the reductions and analyze the data without further recourse to the observing agency.

OPERATIONS

1. Instruments

a. Pyrheliometer. - The instrument used for measurements of solar radiation for the purposes of this project was the Eppley Thermoelectric Pyrheliometer. This instrument (see Mfgr's circular) consists of two concentric rings of equal area, one blackened and the other white coated. The hot junctions of a multiple couple thermopile of gold-palladium and platinum-rhodium alloys are attached to the lower side of the black ring. The manufacturer supplies models with various numbers of junctions, according to the sensitivity required. For solar radiation 10 junctions are usually provided; for measuring the weak reflected radiation from the ground and clouds 50-junction models were sometimes used. The differential in temperature between the two rings when radiation falls upon them creates an electromotive force that is nearly proportional to the amount of radiation received. The rings are mounted horizontally in the center of a thin spherical glass bulb which is sealed with dry air within to prevent moisture from condensing .

This instrument is sensitive to solar and sky radiation with wave lengths between 0.292 and 2.5 μ The lower value is the cut off by the atmosphere and the higher value is the cut off by the glass cover of the pyrheliometer.

b. Recorder. - The instrument which integrates the electromotive force from the pyrheliometer was the Brown "Electronik" strip Chart Potentiometer. This piece of equipment employs a conventional null-balance measuring circuit, but differs basically from the conventional potentiometer in its balancing operations. Instead of the usual galvanometer and its associated mechanisms, the Brown "Continuous Balance" unit is used, an electronic detector which makes possible full advantage of thermocouple responsiveness, unprecedented sensitivity, ruggedness and simplicity. It requires 110V 60 cycle AC circuit for operation. A rotary-type inverter changes the regular DC power of the plane to this required power.

Two pyrheliometers are mounted on each aircraft. Both were connected to the recorder. The electromotive force being generated by each was recorded alternaltely approximately every fifteen seconds on a continuously moving chart. A small numeral "1" or "2" appears beside each recorder mark for the purpose of indentification. The scale panel is divided into divisions numbered from 0 - 100. A full scale deflection is equivalent to 5 millivolts.

c. Mount. - It was necessary that a suitable means be found to mount the pyrheliometer in the aircraft. At present the mount consists of a plate to which the pyrheliometer is attached. Three leveling screws attached to the plate provide a means of leveling the filament of the pyrhiliometer. The mount is constructed in such a manner that the bulbs may be removed or exchanged in flight.

2. Operating Procedures

a. On the Ground: -

(1) See that the recorder is operating satisfactorily when connected to the pyrheliometers.

(2) Short out the top pyrheliometer and observe the position of the recorder mark with reference to the zero line of the chart.

b. Immediately After Take Off.- After take off and when the plane has reached a convenient altitude, ask the pilot to fly as level as possible and level the pyrheliometers.

c. For Measuring Surface Albedo:

(1) Terrain (in general):

(a) This requires more or less cross-country flights. It is suggested for example that a flight from Fairfield to Washington via the Mojave Desert region would serve well to determine how changes in terrain and vegetation conditions affect albedo. Long flights across the country in other directions are desirable.

(b) Fly level as close to the surface as is safely possible.

(c) Make frequent notes on the color and nature (water, forest, sand, etc.) of the terrain below, timing each broad change.

(2) Snow Covered Terrain:

(1) Some flights should be made about 1000 ft. above a flat surface covered by a fresh snowfall. There should not be any vegetation penetrating through the snow if possible. With no new snowfall meanwhile, fly a second mission about two days later in order to measure the change of the albedo with time on the same track and snow layer. It would be desirable to continue these flights every two days as long as the particular snowfall cover lasts.

(3) Ocean Albedo. - The ocean flights should be made on clear days, preferably; one flight if possible when the ocean surface is rough, another when smooth (calm air), about 1000 ft. above the sea surface, with continuous measurements (except when maneuvering, turning, climbing or descending) from solar noon to near sunset, to be made by repeated flights back and forth between two points not less than 25 minutes flying time apart, over deep water. It is important during over-water measurements to frequently observe the intensity and type of roughness of the water, to estimate the swell characteristics as distinct from waves, and to estimate the wind speed at the water surface.

d. Absorption by Clouds. - This requires two-plane flights, one above the clouds, the other directly below, both as near 500 ft. vertical distance from the cloud as feasible; the two aircraft should keep in the same vertical axis as near as possible, by means of radar - the top plane tracking the plane below the cloud layer. It is recommended that such measurements be limited to solid overcasts, preferably thick layers.

e. Flight over Cloud System of a Cyclone. - This requires a flight around the cyclone center at a bout one hundred-fifty or two hundred miles radius, the flight to be about five hundred feet above the couds, to be followed by a flight across the center of the cyclone. Careful notes should be kept at all times of the plane position and cloud conditions, and notes made of the time intervals during which the aircraft is in level and non-level flight. Time checks should be made on the potentiometer at least every half hour, and in addition each time there is some marked change in the cloud system. Photographs of the clouds, with time indicated, would be an extremely useful supplement to the record. If possible coordinate with the Weather Bureau ground pyrheliometer stations.

f. Absorption by Atmosphere. - This is obtained by a series of ascents and descents in clear sky, made by 5000 foot stages, leveling the aircraft over a short fixed path at each stage.

g. Miscellaneous Remarks:

(1) Time checks should be made on the recorder sheet at least once every hour.

(2) Make an occasional zero check; this is done by attaching a clip lead across the terminals of the top pyrheliometer.

(3) Data sheets (see appended forms) are kept by the Navigator and Weather Observer. These sheets plus the rolls from the recorder give all the raw data necessary for the computation of albedo values.

3. COMPUTATIONS

The two constituents resulting from a successful albedo flight are the pyrheliometer record and the flight log. The pyrheliometer record consists of printed records from both the upper and lower pyrheliometers, an occasional "zero check", and frequent time marks supplied by the observer. The flight log contains aircraft data (altitude and heading with times of change of each, indicated air speed, and approximate location), meteorological data (free-air temperature; type, amount, thickness, and general appearance of clouds; and visibility), and supplementary data (type of terrain, air transparency, etc.). These two components should supply enough information for albedo computations.

A careful perusal of the pyrheliometer record should first be made to determine whether the frequent timemarks agree with the rate at which the recorder prints. Minor timing adjustments are often necessary to smooth out discrepancies. After the record has been correctly timed, the next step is to discard those sections of the record during which the plane was changing altitude and/or heading, since the pyrheliometers were not horizontal at those times. The remaining portions of the pyrheliometer record should then be broken into small time units. (Five-minute intervals should suffice except during times when the recorder trace is changing rapidly. Two and one-half minute intervals are then required). Since the recorder paper is ruled into ordinates, the average ordinate value for each time interval should be obtained for each pyrheliometer trace. These average ordinate values must be adjusted if the "zero checks" do not fall on the zero ordinate line.

Next, the correct average ordinate values are converted to "Indicated Millivolts". Since the full scale of the recorder paper is equal to an established number of millivolts in each time unit. However, since the pyrheliometers have been calibrated at a temperature of about 15° C and the air temperature at plane level might be considerably different (usually lower), a small temperature correction is necessary to determine the actual number of millivolts (usually smaller than the indicated millivolts). The correction equation is

Millivolts = Indicated millivolts (1- .004 (15-T)), where T is temperatue in degrees centigrade.

The actual millivolts from each pyrheliometer is then converted to radiation values. The e.m.f. developed by each pyrheliometer has been carefully determined at the factory and a calibration factor supplied with each instrument. The ratio of the actual millivolts developed by each pyrheliometer to the calibrated e.m.f. is equal to the radiation received on each instrument. The radiation values are in units of gm cal/cm2/min, also known as ly/min [1]. The albedo values are the ratios of the radiation received by the bottom pyrheliometer (reflected radiation) to the radiation received by the top pyrheliometer.

[1] Science, Vol. 106, No. 2749, Sept. 5, 1947, p. 225; or Bull. Amer. Met. Soc., Nov. 1947, p. 443.

This procedure is adequate if the measurements have been made when the solar altitude is greater than 30°. However, if the atmosphere is clear above the airplane, and the solar altitude is less than 30° during the measurements, a correction to the radiation value for the upper pyrheliometer is necessary; and this correction becomes more serious as the solar altitude decreases. Therefore, if possible, measurements should be taken near noon.

The correction for low solar altitude is applied in the following manner. When the sun is less than 30° above the horizon, a small amount of direct solar radiation is reflected, rather than absorbed, by the receiving surface of the upper pyrheliometer. The instrument, however, measures the total of both direct (solar) and diffuse (sky) radiation. It must be determined, therefore, what part of the total measured radiation is due to direct sunlight, and what part is due to sky radiation. In his 1919 paper Kimball [2] presents data (from three stations) of the percent of radiation due to direct sunlight at various zenith distances of the sun. From a curve of these data the amount of radiation due to each component part can be readily determined. From a curve of data supplied by the National Bureau of Standards the correction to be applied to the direct solar component is obtained. The actual amount of total radiation, then, is the corrected direct radiation plus the measured diffuse radiation.

Finally, the albedo values are the ratios of the radiation received on the bottom pyrheliometer (reflected radiation) to the corrected radiation received on the upper pyrheliometer (total solar and sky radiation).

To determine the solar altitude, which is needed for the low sun correction, as well as for correlation with the radiation and albedo values, see the navigator or proceed as follows: As all times must be converted to True Solar Time in order to compute solar altitudes, the exact positions of the plane must be known. The most feasible method is to "graph" the path of the aircraft on a map, utilizing and correlating the flight log data. With such a flight graph, the latitude and longitude of the plane at any given time can be really determined.

To convert to True Solar Time, the flight times must first be expressed as standard times. (Although any standard time meridian may be used, it is more practical to use that one nearest the actual position of the plane.) By means of the flight graph, determine the longitude of the plane to the nearest 15 minutes. If the plane is east (west) of the standard meridian used, add (subtract) one minute of time for each 15 minutes of longitude deviation from the standard meridian. The result is the Mean Time. "The American Ephemeris and Nautical Almanac" lists, for any given day, the equation of time or the difference between Mean Time and what results in True Solar Time (TST).

Solar altitudes are determined by use of "Tables of Computed Altitude and Azimuth". [3] From a Nautical Almanac determine the declination of the sun

(2) H.H. Kimball, "Variations in the Total and Luminous Solar Radiation with Geographical Position in the United States", Monthly Weather Review, 1919, 47: 769-793.

on the given day. From the given time (TST), determine the hour angle. (3) (Hour angle is the amount of time away from True Solar Noon expressed as degree of arc, where one degree of arc equals four minutes of time.) From the flight graph determine the latitude of the plane at the given time. Knowing the solar declination, the hour angle, and the latitude, the solar altitude is read directly (or interpolated) from the above quoted tables. (3).

An alternate method for determining solar altitudes is by use of a Solar Altitude Chart. (4). On this chart the grid is designed so that solar altitude values throughout a given day fall along a straight line. Thus, for a given latitude on any specific day, solar altitudes for only two different times need be computed. When the two points are connected, the solar altitude values may be read directly from the chart. Since the pyrheliometer record is divided into time units up to five minutes in length, the computed solar altitude should be an average value during the time interval under consideration. (This is especially true at large hour angles when the sun in changing altitude rapidly.)

SAMPLE

Information from pyrehliometer record:

100 ordinates = full scale = 5.0 millivolts

TIME (EDST)	AVERAGE ORDINATE VALUE		ZERO CHECK
	UPPER PYRHEL.	LOWER PYRHEL.	
0830	28.2	26.6	+ 0.2

Time indicated is average time during a 5 minute interval.

Information from flight log:

Free air temperature at 0830 EDST = 2°C.

Date September 15, 1947.

0830 EDST

I. Actual Ordinate Value
Since the zero check is + 0.2, the recorder is printing 0.2 ordinates too high.

Upper Pyrheliometer		Lower Pyrheliometer
28.2	Average ordinate value	26.6
-0.2	Correction for Zero Check	-0.2
28.0		26.4

(3) "Tables of computed Altitude and Azimuth", United States Navy Department, Hydrographic Office, 8 Vols. (H.O. 214)

(4) Described by Schutte in Met. Zeit., Aug., 1931

II. Indicated Millivolts

Since 100 ordinates = 5.0 millivolts, each unit ordinate $= \frac{5}{100} = .05$ mv.

Upper Pyrheliometer
X = 28.0 x .05
X = 1.40 indicated millivolts

Lower Pyrheliometer
X = 26.4 x .05
X = 1.32 indicated millivolts

SAMPLE

III. Millivolts corrected for Temperature

Application of the temperature correction equation gives:

Upper Pyrheliometer

Millivolts = 1.40 (1-001 (15 + 2))
= 1.40 (0.983)
= 1.38

Lower Pyrheliometer

Millivolts = 1.32 (1-.001 (15+2))
= 1.32 (0.983)
= 1.30

IV. Indicated Radiation Values

Upper Pyrheliometer

1.38 Millivolts corrected for temperature
÷ 2.06 Mv. per ly/min
(Calibrated emf supplied each pyrheliometer)
0.67 ly/min

Lower Pyrheliometer

1.30
÷6.52

0.20

V. True Solar Time

From the flight graph the longitude of the plane at 0830 EDST is found to be 78° 45' W.

0830 (h m)	EDST
-1^h	
07^h30^m	EST
-15^m	(3° 45' West of 75th meridian)
07^h15^m	Mean Time
+ 5	(Equation of Time, from "American Ephemeris and Nautical Almanac," 1947).
07^h20^m	True Solar Time

VI. A. Solar Altitude

Declination of sun = + 3° 10' (From Nautical Almanac, 1947)
True Solar Time = 07^h20^m
Hour Angle = 70° ((12^h00^m - 07^h20^m) ÷ 4^m/deg.)
Latitude = 35°00'N (From flight graph)

From "Tables of Computed Altitude and AZimuth", Vol. IV, using latitude and hour angle, the following solar altitudes are read:

18° 02.9' (for declination + 3° 00')
18° 20.4' (for declination + 3° 30')
Interpolating for declination + 3° 10':
Solar Altitude = 18° 09'

SAMPLE

B. Solar Altitude (alternate method)

On the attached sample Solar Altitude Chart a straight line for September 15 has been computed and drawn. The value read from this chart is (for 0720TST):

Solar Altitude = 18° 10'

VII. Actual Radiation Value

Radiation indicated by upper pyrheliometer = 0.67 ly/min
Solar Altitude = 18° 09'

Percent of indicated radiation due to sun = 74.3 - from attached
Percent of indicated radiation due to sky = 25.7 -curve of data from Kimball

Amount of indicated radiation due to sun = 0.498 ly/min (0.67x74.3%)
Amount of indicated radiation due to sky = 0.172 ly/min (0.67x25.7%)

Direct solar correction value = 0.935 0.935 (from curve of correction values)

Actual amt. of radiation due to sun = 0.533 ly/min (0.498 ÷ 0.935)
Actual amt. of radiation due to sky = 0.172 ly/min (indicated = actual)

Actual amt. of total radiation on upper pyrheliometer = 0.705 ly/min

(Note that no corrections are necessary for the Indicated Radiation received by the lower pyrheliometer since direct sunlight is not involved.)

VIII. Albedo Value

Radiation on upper pyrheliometer = 0.705 ly/min

Radiation on lower pyrheliometer = 0.20 ly/min

Ratio of lower to upper pyrheliometer = 0.284
Result: Computed albedo for 0830 EDST on September 15, 1947 is 28.4%

4. ACTIVITIES

a. The project was activated during February 1947. From then until 1 June 1948 when the present project officer, Lt. Walter E. Warner, was assigned, the following officers were directly concerned with the conduct of the project: Major John G. Hemans, Major William P. Mellen, Capt. Robert L. Houghten and Capt. James O. Vann.

b. The period February 1947 - June 1948 was spent in preliminary coordination regarding general aspects of the project. The type of instruments to be used was decided upon, procured, tested, and installed. An operational SOP for making pyrheliometric measurements from the B-29 was decided upon during that period.

c. Instruments:

(1) During a conference at Headquarters, Air Weather Service, 14 Feb 1947 it was stated that sufficient equipment had been ordered to equip one aircraft and to have sufficient spares to maintain operation.

(2) On 21 March 1947, Major Mellen in a letter to Major Hemans described the type of equipment used on the B-29 assigned to Project Apollo. The mount used on this plane was explained in detail with dimensions.

(3) Major Mellen flew in a modified B-29, 22 March 1947, to Inyokern, California which is the location of the Naval Ordnance Test Station. In this report was noted for the first time the fact that the white magnesium oxide surface of the filament of the pyrheliometer was flaking noticeably.

(4) A measurement of loss of sensitivity due to oil on the bulb was made 25 March 1947. Larger amounts of oil on the glass surface than had ever been observed on the bulb of an instrument on the plane attenuated the incident sunlight by less than 2%.

(5) One of the pyrheliometers was rendered inoperative by a slight jar 26 March 1947 and two days later the glass stem of another pyrehliometer was broke during a flight.

(6) For the summer of 1947 the Albedo file is rather incomplete. It is assumed that during this period modification plans were discussed, equipment was being received, and permission was being requested to modify aircraft. It must be remembered that during this period the 308th Reconnaissance Group (Weather) was moved from Florida to California.

(7) Two aircraft were finally depot modified and returned to Fairfield in early April 1948. An attempt was made to take some albedo measurements during flight from the depot, but both pyrheliometers failed.

(8) The project officer, Lt. Walter E. Warner, accompanied by Mr. R.G. Stone of Headquarters, Air Weather Service proceeded on 23 June 1948, to Eppley Laboratories, Newport, R. I., the manufacturer of the pyrheliometers. All damaged pyrheliometers, together with a case history of how each was used before failure occurd, were shown to Eppley engineers. The Eppley engineers also were acquainted with the vibrations, etc., relative to aircraft operation so that they might possibly develop a pyrheliometer which would endure aircraft operation.

(9) Three new model pyrheliometers, reported to be able to withstand aircraft operations, were presented to the project officer by the Eppley Laboratories for flight test on 4 Aug 1948. Several flights were made from Bolling AFB for test purposes, each flight being followed by rough landings. All the pyrehliometers functioned perfectly. One of the bulbs was later broken accidently, but all the other bulbs have now experienced approximately 150 hours of mounted operations.

(10) During the period July-October 1948 a new type mount was conceived, designed, assembled, and installed on one of the Albedo-modified aircraft. This mount makes possible the removal and replacement of pyrheliometers during flight. A new, improved means of leveling the pyrheliometer has been incorporated into the new mount.

(11) The Brown recorder has always functioned perfectly. A recent check showed both recorders used in the project to be holding their calibration satisfactorily.

d. Operations:

(1) A joint mission was flown 6 May 1948 with a plane from Inyokern. The absorption of radiation by a stratus layer was measured with good results.

(2) Some usable terrain albedos were obtained during a flight to Washington D. C. on 4 Aug 1948. The following day a short mission lasting one hour was flown in the vicinity of Washington. An additional flight across New York State was made 9 Aug 1948 and finally 11 Aug 1948 the return flight was made to Fairfield.

(3) During the period 7 Sept 1948 - 18 Sept 1948 a series of flights were made over the U.S. These flights were planned to pass over all possible types of terrain as follows:

1 Fairfield-Boise-Crater Lake-Fairfield

2 Fairfield-Salt Lake City-Salina-

3 Salina-Oklahoma City

4 Oklahoma City-Dayton, Ohio

5 Dayton -Wisconsin-Dayton

6 Dayton-Macon, Georgia via eastern seaboard

7 Georgia-Barksdale Field, La.

8 Barksdale-Fairfield via Southern California

(4) A mission was flown 20 September 1948 off the coast of California for the purpose of measuring the albedo of water. Clouds prevented measurements for any extended period of time but some good readings were obtained.

(5) Mr. T. W. McDonald, U.S. Weather Bureau, arrived Fairfield 30 October 1948 to assist in the project. A two plane mission was flown 2 November 1948 to measure the absorption of a cloud layer. Excellent results were obtained.

(6) During a flight to Washington 16 November 1948 another two plane mission was flown.

(7) During return flight from Washington 18 November 1948 the albedo of the cloud system around a low pressure area was measured.

(8) During the last week in November a mission was flown in the vicinity of Death Valley to measure the absorption of the clear atmosphere. Flights were made over a fixed path from sea level to 30,000 ft.

(9) During the period 10 April - 28 April 1949 four single-plane missions were flown from Andrews AFB, Maryland. These flights, made over Weather Bureau solar radiation stations at Washington, Boston, and Cape Hatteras, were designed to measure the loss of solar radiation by passage through cloud layers.

(10) The data obtained on the missions described in the preceeding paragraphs has been assembled but is not reproduced here because it would necessitate copying many hundred feet of chart roll. All data is presently on loan to the U.S. Weather Bureau where much of it will be reduced for the use of interested research agencies.

CONCLUSIONS

1. Instruments

a. Pyrheliometers: New type bulbs have been flight tested for a sufficient number (150) of hours to consider them satisfactory for aerial use.

b. Brown "Electronik" Recorder: This piece of equipment has functioned extremely well on all occasions. Its range and accuracy is such as to qualify it for future albedo purposes.

c. Mount: The type in use at the present is perfectly satisfactory for limited experimental work, provided that an operator stands by to level the mount when necessary. If, in the future, albedo measurements are to be taken by a considerable number of aircraft on routine weather missions, it would seem to be highly unlikely that an extra crew member could be added for this purpose. Hence it would be necessary to devise a remotely operated mount which would be leveled by gyro means or possibly by mercury switches.

2. Calculations

A description of the calculations used to obtain actual values is given elsewhere in this report. The calculations are satisfactory but consideration must be given to the fact that it is possible to spend from ten to fifteen minutes to reduce data that was obtained over a period of five minutes. The present supply of available personnel at squadron level would seem to preclude the reduction there of the mass of data which would be obtained on many flights.

3. Operational Procedures

The procedures described have been found to be basically sound. Some slight obvious changes are necessary occasionally to obtain the best possible measurements from a given weather situation.

4. Missions Flown

The missions flown have at least given a small sampling of all types of measurements asked for except those over snow cover. Definite conclusions on the values of albedo must await final reduction of data . However, scientific conclusions should be based on a more generous sampling of data.

RECOMMENDATIONS

As long as albedo flights are only of an experimental or limited investigational nature and flown by a single aircraft the present pyrheliometer mount is satisfactory. However, if flights should be planned on a larger scale, for example by several aircraft in each operating weather reconnaissance squadron, it is recommended that a gyro-stabilized mount be developed for reasons discussed above. A gyro-mount together with a Brown Recorder and a suitable supply of pyrheliometers could be assembled in kit form for distribution to the squadrons as a standard modification. Personnel from each squadron should spend some time at Fairfield for indoctrination in albedo techniques.

In future procurement of pyrheliometers for airborne albedo measurements, it is recommended that only 10 or 20 junction models be purchased. These 10-20 junction bulbs are suitable for all purposes, whereas, the 50-junction type cannot be used to measure direct solar radiation with the present recorder.

APPENDIX

ALBEDO PROJECT
WORK SHEET
NAVIGATOR

PYRO CONSTANTS

DATE ________

Upper # ______ ; ______ MV min. cm./gm.cal.

OBSERVER ________

Lower # ______ ; ______ MV min. cm./gm.cal.

TIME PDT	POSITION LAT. LONG.	IAS	TAS	MAG. HDG.	GS	WIND WD/WV

ALBEDO PROJECT
WORK SHEET
NAVIGATOR

Weather Observer

DATE ________

OBSERVER ________

TIME PDT	CLOUDS ABOVE -/10	TYPE	BASE	TOP	BELOW -/10	TYPE	BASE	TOP	TERRAIN FEATURES

ALBEDO PROJECT
WORK SHEET

Weather Observer

DATE ________

OBSERVER ________

TIME PDT	PRESS ALT	RADAR ALT	ALT SET	TIME ROLL MARK	TIME PDT	PRESS ALT	RADAR ALT	ALT SET	TIME ROLL MARK